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Quinoa growth and yield performance in Tanzania: A prospect crop for food security

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Abstract

Quinoa is an emerging potential cereal crop that has recently been recommended for food security worldwide. This study was to evaluate growth and yield performance of quinoa genotypes under rain-fed conditions at the Nelson Mandela African Institution of Science and Technology (NM-AIST) farm in Arusha and Kibosho (KB) in Kilimanjaro during the 2018/2019 growing season in Tanzania. The experiment had five genotypes (QQ74, Titicaca, Multihued, Biobio and Brightest Brilliant Rainbow) laid out in a randomized complete block design with four replications. Parameters evaluated were days to 50% flowering and maturity, panicle length, grain yield/ha, above-ground biomass, seed size (g/1000 grain weight) and harvest index. Data was analyzed by Gen-stat statistical package. The results showed that growth and yield performance of the five quinoa genotypes at the NM-AIST and Kibosho differed. Interaction of genotype and site significantly ($P<0.001$) influenced days to 50% flowering and plant height. The genotype × site interaction significantly ($P < 0.05$) affected panicle length, days to maturity, biomass and harvest index. Grain yield was higher at the NM-AIST (ranging from 3194 to 4306 kg/ha) than Kibosho (ranging from 2778 to 3917 kg/ha). The highest yielding genotype at both sites was BBR. The results strongly showed that quinoa can grow well in the Tanzanian environments, thus the crop can be introduced to Tanzania. Quinoa has a potential of addressing food and nutritional security due to its ability to adapt to a wide range of environmental condition and its high nutritional profile.

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Introduction

Quinoa (*Chenopodium quinoa* Willd) crop originated from South America in the Andean region where it was domesticated 3,000 to 4,000 years ago as a food crop (Jacobsen, 2003; Fuentes *et al.*, 2009). For years, the main producers of quinoa have been Peru, Ecuador, Chile, and Colombia, until recently when quinoa gained wide interest, and its cultivation is spreading globally (Lopez-Garcia, 2007; Sharma *et al.*, 2015). Quinoa is an emerging potential cereal crop that has recently been recommended for food security worldwide (Maliro *et al.*, 2017). Among other common grains, quinoa is considered unique due to its outstanding nutritional composition and tolerance to adverse climatic conditions, both biotic and abiotic stresses. Over the years, the demand for quinoa on the international market has significantly increased hence its production has also increased in countries such as India, Canada, Australia, China and the United States (Fuentes *et al.*, 2009; Pulvento *et al.*, 2010; FAO, 2011; Kansomjet, 2017). As one of the emerging cereals with potential for food security, quinoa is rich in high-quality proteins with a balanced set of essential amino acids such as tryptophan, histidine, valine, lysine, tyrosine, leucine, isoleucine, phenylalanine, methionine and threonine. In terms of biological value, proteins found in quinoa are said to be higher than protein found in meat and milk (Izquierdo *et al.*, 2003a; Izquierdo *et al.*, 2003b; Jacobsen and Christiansen, 2016). In 1993, Ranhotra *et al.* (1993) reported that quinoa has high-quality protein which is attributed to its composition of amino acids; albumin and globulin, which are equivalent to the casein, protein milk. Composition of minerals such as calcium, iron, and phosphorus in quinoa is high compared to other cereals such as maize (Jacobsen *et al.*, 2009; Rosa *et al.*, 2009; Vega-Gálvez *et al.*, 2010; Adolf *et al.*, 2013; Shabala *et al.*, 2013; Jacobsen and Christiansen, 2016; Walters *et al.*, 2016).

Besides nutritional importance, the quinoa plant offers wide adaptability to diverse environmental conditions, mainly drought and salinity, making it a suitable crop for food security especially in harsh conditions (FAO, 2011). The drought tolerance in quinoa is said to be attributed to the branched and taproot system that quinoa plant has that penetrates up to 1.5 m (Zurita-Silva *et al.*, 2015). Quinoa plant also has an inherent low water requirement and amplitude to quickly resume to its former photosynthesis level and its definite leaf area after a dry period (Jacobsen, 2003; Jacobsen *et al.*, 2009). Furthermore, quinoa is tolerance to alkaline or acidic soils unlike most cereals and can even grow better under arid conditions (Vega-Gálvez *et al.*, 2010; Walters *et al.*, 2016). However, recent reports in Africa, have shown that food security situation has worsened especially in the sub-Saharan part where the prevalence of under-nutrition was reported to be at 22.7% having one-third of the population estimated to be malnourished (FAO *et al.*, 2017). Within sub-Saharan Africa, experiments have been conducted in Uganda, Ghana, Zambia, Chad, Djibouti, Burkina Faso, Mali Senegal, Somalia, Sudan, Guinea, Malawi, and Kenya, (Coulibaly *et al.*, 2015; Bazile *et al.*, 2016; Maliro *et al.*, 2017). Although field trials have been conduction on growth and yield performance of quinoa in other countries, no studies have been conducted in Tanzania.

Tanzania's population is currently over 55 million and of which, over 80 percent depend on maize (Lyimo *et al.*, 2014) as the main staple. However other cereals such as rice, sorghum and wheat, are also cultivated as source of energy. The production of these cereals has greatly affected by climate change, and their production has been predicted to reduce (Brinda *et al.*, 2014; Adhikari *et al.*, 2015). Recently, Matata *et al.* (2019) conducted a study assessing rainfall and temperature changes in semi-arid areas of Tanzania, and results have shown considerable rainfall and temperature variability within and between seasons characterized by short rainfall and increased frequency of droughts (Brinda *et al.*, 2014; Matata *et al.*, 2019). A rapid population growth rate that is coupled with unfavorable climatic conditions across the country will negatively affect the availability of food to people resulting in malnutrition, which is also attributed to lack of nutritious food like quinoa (Arndt *et al.*, 2012; Brinda *et al.*, 2014; Zikankuba and James, 2017). There is a need to explore more crop varieties that are nutritious as well as stresstolerant such as quinoa (Choukr-Allah *et al.*, 2016) in order to fill this gap. This study aimed at introducing quinoa cultivation in Tanzania by evaluating quinoa genotypes for plant growth and grain yield performance under different environmental conditions of the northern part of Tanzania. Our specific aim was to identify the genotypes with high yields and superior agronomic characteristics in each location and to test for interaction of genotype and environment that could supply information to breeders to develop new varieties for farmers in Tanzania.

Materials and methods

Germplasm Sources and their description

The Lilongwe University of Agriculture and Natural Resources of Malawi supplied the five quinoa (*Chenopodium quinoa* Willd) genotypes (Table 1). The genotypes were QQ74, Biobio, Multihued, Brightest Brilliant Rainbow (BBR), and Titicaca that are among released varieties of quinoa in Malawi.

Table1. The five quinoa genotypes, source, origin and physical seed characteristics.

Genotype	Seed color	Origin	Seed imported from
Biobio	Cream	USA	Malawi
Brightest Brilliant Rainbow	Cream white	Canada	Malawi
Multi-Hued	Cream white	Canada	Malawi
QQ74	Cream	Chile	Malawi
Titicaca	Cream white	Denmark	Malawi

Description of the Experimental Sites

The experiments were carried out in two sites, the Nelson Mandela Africa Institution of Science and Technology farm (NM-AIST) in Arusha and Kibosho, the outskirt of Moshi town in Kilimanjaro Regions in northern Tanzania. In both sites, the study was laid out during the 2018/2019 growing season. The NM-AIST is located at a latitude of 3.3705°S and 36.6959°E with an elevation of 1208 above sea level. During the study period, the NM-AIST had monthly temperatures ranging from 14 to 35°C and monthly rainfall ranging from 2 to 200mm while Kibosho is located at 3°17′30″S and longitude 37°17′48″E at the elevation of 1084 meters above sea level. Kibosho had temperatures ranging from 14-30°C and monthly rainfall ranging from 5-850mm. Both sites receive bimodal kind of precipitation, whereby the first rains fall between November and January and the second one from March and May. However, the first effective rains for the growing season 2018/2019 delayed and were short, falling between April-May for both sites. The actual locations of the field experiments are shown on the map (Fig. 1).

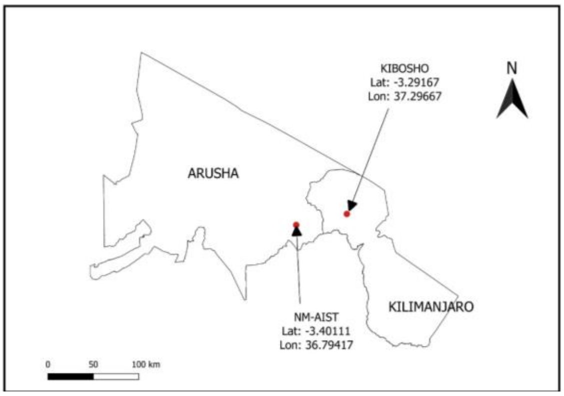

Fig. 1. Map of Northern Eastern Tanzania showing the locations of NM-AIST and Kibosho where the quinoa field experiments were conducted**.**

Soil sampling and analysis

A total of five composite soil samples each weighing 1 Kg from each experimental field of about one acre (1 acre) was obtained from both sites. The soil samples were collected before planting using the soil core at a depth of 0-30cm in a zigzag way. Thereafter, the soil samples were air-dried, ground and sieved through a 2-mm sieve.

Sub-samples for total N and organic C (labile fraction of soil C) analysis were further pulverized to a fine powder (< 0.5mm). The particle size distribution of the soil was determined using the hydrometer method (Kettler, 2001). Soil pH was determined in a 1:2.5 soil: water suspension (Strosser, 2010). Organic carbon was determined by the Walkley and Black method (Nelson and Sommers, 1996). Organic carbon percentage soil was calculated using the formulae below. Organic Carbon(%) =(Blank -Samples)/Soil samples weight (g)x 0.05 x1.3 x 100

A semi-micro Kjeldahl method involving digestion and distillation as described by (Horwitz, 2010) was used to determine total nitrogen in the soils.

On the other hand, cation exchange capacity was determined using ammonium acetate method at pH 7.0 (Ward and Balaban, 2000). Spectrometric, AAS method was used to determine exchangeable bases such as potassium, calcium, magnesium and sodium (Dipietro *et al.*, 1988). Phosphorus was determined by Kurtz and bray 1 method (Sims, 2000) . Also, the percentage base saturate, exchangeable sodium % and C/N ratio was calculated using the formulas below. %BS = (Ca2+ + Mg2+ K+)/CEC x 100 Where BS = Base Saturation and Ca = Calcium, Mg =Magnesium, K = Potassium and CEC = Cation Exchange Capacity
%ESP = (Exchangeable Na)/CEC x100

All the analysis were done in the Tanzania Coffee Research Institute (TaCRI) soil laboratory. The results were averaged to generalize the fertility levels of the experimental sites.

Experimental set-up and data collection

Five quinoa genotypes were planted at the spacing of 20 cm x 10cm [equivalent to plant population sizes of 496 plants ($9m^2$)] in a randomized complete block design with four replications. The experimental unit size was 3 x 3 m having the 1.0 m space between treatment pots and 1.0 m space between blocks for both sites. The quinoa seeds were sown in rows at about 1.5cm depth and covered with a thin layer of soil. Two weeks after emergence, the seedlings were thinned to one seed per station. Yara cereal fertilizer (23N: 10P 15K+2Mg 0.3S + 0.3Zn) was used as a source of nitrogen, phosphorus, and potassium. Weeding was conducted twice to maintain the field free from weeds. The whole treatment plot ($9m^2$) was used as a net plot. A broad-spectrum insecticide (Dudu Will EC) was used to control insect pests as they appeared. Rainfall and temperature data for the two sites were recorded. Data on growth and yield parameters collected include; Number of days to 50% flowering, number of days to maturity, panicle length (cm), plant height (cm), grain yield per hectare (kg), seed size (g/1000 seeds), dry biomass per hectare (kg) and Harvest index. The harvest index was calculated using the formula indicated below. Harvest index = (Weight of grain (kg))/ (Grain weight + Brushwood weight (kg)) Where HI= Harvest Index, GW= Grain Weight, and BW= above-ground vegetative Biomass Weight.

Statistical Analysis

The data were subjected to Analysis of Variance (ANOVA) using Genstat Software (15^{th} edition) where genotype and site were considered the only factors used in the analysis. Treatment means were compared using the Tukey test at 5% level of significance. Regression analysis was used to measure the association between variables.

Results

The two sites varied in temperatures and rainfall received during the 2018/2019 growing season. NM-AIST (Fig. 2) received slightly higher temperatures as compared to Kibosho (Fig. 3) likewise the rainfall. The rainfall ranged from 5- to 32.7mm and 4.7 to 196.5mm at NM-AIST and Kibosho respectively.

Weather during the experimental period

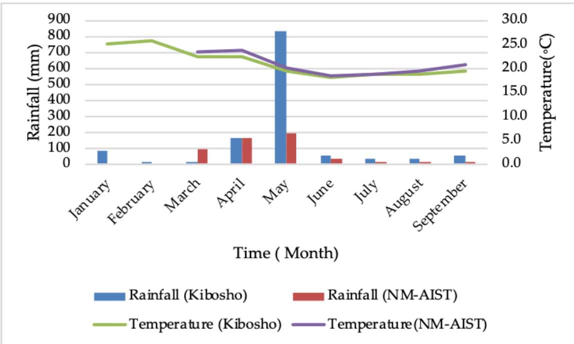

Fig. 2. Shows the temperatures and rainfalls for the two study sites for March- September at NM-AIST and January-September at Kibosho.

Soil fertility status for NM-AIST and Kibosho sites

NM-AIST

Soils at NM-AIST experimental site had a pH value of 6.4, rated as slightly acidic, suitable for cultivation of most crops including quinoa. The soil had medium organic carbon (1.40%) corresponding to medium organic matter (2.41%) and exchangeable magnesium, very low nitrogen (0.08%), very high potassium (2.5 cmol (+)/kg), very high available phosphorous (23.43 mg/kg) and exchangeable calcium (16 cmol (+)/kg); this classify that, the soil fertility status is medium, which is moderately suitable for quinoa cultivation.

Kibosho

Soils at Kibosho experimental site had a pH value of 5.3, rated as acidic. The soils in this site might be affected by Al toxicity and excess of Co, Cu, Fe, Mn, Zn and deficiencies of K, N and P. The soil had medium organic carbon (1.7%) corresponding to medium organic matter (2.9%), very low nitrogen (0.09%), very low potassium (0.8 cmol (+)/kg) and low available phosphorous (6.8 mg/kg) and very high exchangeable calcium (11.24 cmol(+)/kg): this classify that, the soil fertility status is low, necessitating supplementation of these nutrients for quinoa cultivation.

Table 2. Summary of physical and chemical properties of soils from the two experimental sites: NM-AIST and Kibosho

Soil Parameter	Site	
	Kibosho (n=5)	NM-AIST (n=5)
Soil pH	5.30 ± 0.077	6.40 ± 0.07
OC (%)	1.71 ± 0.18	1.404 ± 0.12
TN (%)	0.09 ± 0.002	0.08 ± 0.008
P (mg kg-1)	6.08 ± 0.37	23.42 ± 2.37
K (cmol kg-1)	0.80 ± 0.005	2.504 ± 0.223
Ca (cmol kg-1)	11.24 ± 0.80	16.08 ± 0.81
Mg (cmol kg-1)	1.76 ± 0.22	0.966 ± 0.80
BS (%)	91.00 ± 1.90	81.20 ± 2.51
CEC (cmol kg-1)	15.20 ± 0.70	24.40 ± 1.30
ESP (%)	1.40 ± 0.20	0.94 ± 0.13
Sand (%)	70.08 ± 1.70	37.04 ± 1.70
Clay (%)	5.88 ± 0.25	28.56 ± 3.82
Silt (%)	24.04 ± 1.50	34.40 ± 2.10
Textural class	sandy loam	clay loam

ESP=Exchangeable Sodium Percentage, OC=Organic Carbon, TN= Total Nitrogen, C/N=Carbon nitrogen ration, CEC= Cation Exchange Capacity, Mg=Magnesium, Ca= Calcium, BS=Base saturation, pH (H_2O) =Soil pH in water, P= Phosphorous, K= Potassium, and Aval P= Available phosphorous

Number of days to 50% flowering and maturity

There was a significant (P<0.001) interaction between the genotypes and sites. The genotype QQ74 was the latest to to reach 50% flowering in both sites compared to other genotypes. There was strong association between 50% flowering and days to maturity. The varieties that flowered early were also the early to reach physiological maturity. Similarly, QQ74 took more days to reach 50% flowering and affected days to maturity.

A significant (P<0.001) interaction in days to maturity was observed among the genotypes and sites. The genotype QQ74 took approximately 101 days to reach physiological maturity stage at NM-AIST and 79 days at Kibosho.

Plant height

Site × genotype interaction affected plant height of quinoa genotypes. The study revealed that the QQ74 genotype had the longest plant height of 117.4cm and 96.9cm at NM-AIST and Kibosho, respectively (Table 3). The plants at Kibosho were generally shorter with a grand mean height of 93.76cm as compared to those at NM-AIST (111.6cm).

Panicle length

The length of panicles significantly varied (P < 0.001) between sites and among genotypes. Plants at NM-AIST site had longer panicles as compared to Kibosho. BBR and QQ74 statistically had the longest panicles of 45.55cm and 46.95cm respectively, at NM-AIST. However, at the Kibosho site, Titicaca and BBR had the longest panicles with a panicle length of 42.5and 41.9cm respectively.

Table 3. Growth and yield parameters of five quinoa genotypes grown at NM-AIST and Kibosho sites in Tanzania under rain-fed conditions.

Genotype	Days to 50% flowering		Days to maturity		Plant height (cm)		Panicle Length (cm)	
	NM	KB	NM	KB	NM	KB	NM	KB
Titicaca	42a	43ab	75.5a	76.75a	115.2de	85.3a	42.13bc	42.5bc
Biobio	45b	41.5a	79.25a	78.25a	108.5cde	97.3ab	38.3bc	27.65a
Multihued	43.25ab	42a	75.25a	81.5ab	104.1bcd	94.4ab	43.15bc	39.5bc
BBR	42a	42a	77.25a	73.25a	112.2de	95ab	45.55c	41.9bc
QQ74	53.5c	43.25ab	100.5c	90b	117.4e	96.9ab	46.95c	34.8ab
Mean	45.15	42.35	81.55	79.95	111.6	93.76	43.22	37.27
LSD (0.05)	1.267		5.692		6.923		6.268	
Variety (P-value)	<0.001		<0.001		0.021		<0.001	
Site (P-value)	<0.001		0.208		<0.001		<0.001	
Variety ×Site (P-value)	<0.001		0.004		0.002		0.037	
±SE	0.437		1.962		2.386		2.16	
CV%	0.7		1.2		2		4.2	

Grain yield

Results presented in table 4 indicate that there was a significant difference (P <0.001) in grain mean weights obtained among genotypes and between sites. However, no significant difference (P=0.834) was observed from an interaction between the genotypes and sites. The genotypes yield at NM-AIST site was higher compared to those grown at Kibosho. The results revealed that the BBR genotype ranked the highest in grain weight (4306 kg/ha) at NM-AIST, followed by Titicaca (4056kg/ha) and the least grain yield was obtained from the genotype QQ74 (3194 kg/ha). However, at the Kibosho site, the genotype, BBR had the highest grain weight (3917kg/ha) while Biobio was the least (2574kgs/ha).

Biomass and Harvest Index

Genotype × site interaction significantly (P<0.05) affected biomass. Generally, the NM-AIST site had higher biomass than Kibosho. The genotype QQ74 obtained the highest biomass (7556 kg/ha) followed by BBR (7167 kg/ha) and the least biomass was obtained from Biobio (5833 kg/ha). At the Kibosho site, however, BBR gave the highest biomass (6722kg/ha) followed by QQ74 (5417kg/ha) while multihued gave the smallest biomass of (3759kg/ha).

Surprisingly, the genotype QQ74 that gave the smallest grain yield had the highest biomass yield at NM-AIST, contrary to the case at Kibosho; the genotypes that had higher yield also gave the higher biomass at Kibosho site. Biomass and harvest index are the indices that are directly related to grain yield. A significant difference (P<0.05) was observed between the interaction of genotype and site. At NM-AIST, the highest harvest index was obtained from BBR and Biobio followed by Titicaca, Multihued and QQ74 obtained the lowest harvest index.

Table 4. Yield and yield components of five quinoa genotypes grown at NM-AIST and Kibosho sites in Tanzania under rain-fed conditions.

Genotypes	Grain weight (kg/ha)		Biomass (kg/ha)		Harvest Index	
	NM	KB	NM	KB	NM	KB
Titicaca	4056bc	3250ab	6944cd	4361ab	0.365a	0.375ab
Biobio	3583abc	2861a	5833bcd	4528ab	0.3825cd	0.3075ab
Multihued	3750abc	3139ab	6611cd	3750a	0.3625abc	0.4075b
BBR	4306c	3917bc	7167d	6722cd	0.3750cd	0.3575ab
QQ74	3194ab	2778a	7556d	5417abc	0.2875ab	0.335ab
Mean	3777.78	3188.88	6822	4956	0.3565	0.3960
LSD (0.05)	626.743		1041.9		0.04385	
Variety (P-value)	<0.001		<0.001		<0.001	
Site (P-value)	<0.001		<0.001		<0.001	
Variety × Site (P-value)	0.834		0.014		0.017	
±SE	215.99		359.1		0.01511	
CV (%)	4.3		4.0		2.9	

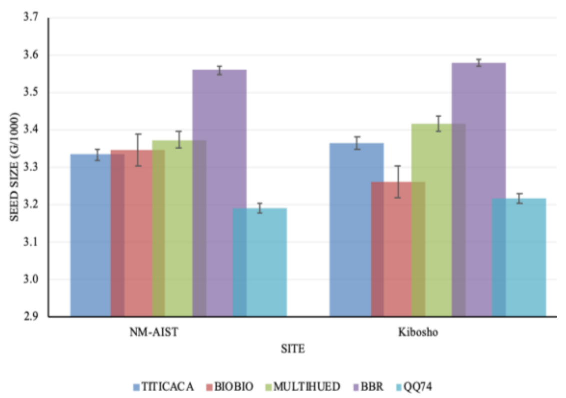

Fig. 3. Seed size (g/1000 seeds) of five quinoa genotypes grown at NM-AIST and Kibosho sites (P <0.05 for genotype, P = 0.834 for Site and P = 0.419 for genotype × site).

Seed size

A significant (P≤0.05) difference in seed size was found among genotypes. However, there was no interaction (P = 0.834) between genotype and site (P = 0.419) (Fig. 6). BBR had the highest seed size (3.6g/1000 seeds) and QQ74 was the least, having 3.2g/1000 seeds in both sites.

Biomass had a positive correlation with grain yield, plant height and had a negative correlation with harvest index. This implies that the harvest index reduced with increasing biomass. There was a positive correlation between days to 50% flowering and days the genotypes took to reach physiological maturity.

However, a significant correlation was observed between days to 50% flowering and harvest index as well. There was a direct positive association between grain yield and seed size. Interestingly, a negative correlation was observed between the harvest index and plant height.

These results are in line with results reported by Maliro *et al.* (2017), however; no correlation was found between the harvest index and biomass or plant height. on the other hand,it also reported a positive association between biomass and grain yield Oyoo *et al.* (2010).

Table 5. Correlation analysis for biomass, grain yield, Harvest index, days to 50% flowering and maturity, plant height and seed size of quinoa genotypes grown at NM-AIST and Kibosho sites in Tanzania under rain-fed conditions.

	Biomass	Days to 50% maturity	Grain yield	Harvest Index	Maturity	Plant height	Seed size
Days to 50% maturity	0.43	-					
Grain yield	0.65**	-0.21	-				
Harvest Index	-0.79**	-0.64**	-0.06	-			
Maturity	0.16	0.84**	-0.53	-0.58	-		
Plant height	0.79**	0.50	0.46	-0.64**	0.32	-	
Seed size	0.07	-0.47	0.65**	0.44	-0.54	-0.04	-
Panicle length	0.62	0.42	0.62	-0.23	0.12	0.41	0.39

Note: **= P<0.05 level of significance

Discussion

The differences in plant height of quinoa genotypes at both experimental sites could be attributed to environmental factors such as soil and rainfall. In addition, genetic factors contributed to the differences in plant height among the genotypes where QQ74 revealed superiority in plant height in both sites. Soil fertility status at NM-AIST site was generally fertile than the soils at Kibosho. The soil from the Kibosho site was acidic limiting nutrient uptake by the plants. However, the soil at NM-AIST site was slightly acidic providing a favorable condition for nutrient availability and uptake that enhances plant growth and development. The findings are in agreement with Maliro *et al.* (2017) where the QQ74 genotype had a higher plant height as compared to the other tested quinoa genotypes.

The high temperature also provided the plants with sunlight, which is essential for its growth and development especially for the first two months whereby photosynthesis is so critical for active plant growth and development. The high temperatures indicate adequate sunlight that hastens the rate of photosynthesis and other enzymatic processes, which are responsible for plant growth. The optimum temperatures for quinoa range between 20-25°C (Bois *et al.*, 2006).

However, in general, temperatures at NM-AIST site during the study period were slightly higher than Kibosho while at the same time slightly falling below and above the optimum temperature range for quinoa. Similarly, Yang *et al.* (2016) reported that lower temperatures significantly reduce photosynthesis system efficiency. Therefore, it is likely that lower temperatures at Kiboshowere accountable for the shorter plant height (Wingler, 2015). Low temperature inhibits plant growth by lowering the rate of photosynthesis and inhibit active cell division and expansion. Panicle length is one of the important yield parameters such that the longer the panicle, the higher the grain yield. Maliro *et al.* (2017) reported that panicle lengths differences were attributed to genotype factors. However, in this study, differences in panicle lengths were attributed due to the interaction of genotype and site.

In the study, variations in the days to 50% flowering were as a result of some inherent factors influenced by the ecological adaptation zone of the genotypes (FAO, 2013). In general, flowering is an essential trait that guarantees seed production. The longer the period the plants take to flower, the more chances of them being vulnerable to environmental stresses (Kazan and Lyons, 2015).

Maturation period for quinoa has been classified as precocious when matures in less than 130 days, semi-early; 130 -150 days, semi late; 150-180 days and late when over 180 days (Belmonte *et al.*, 2018). Therefore, in terms of the number of days to maturity, the genotypes used in this study belong to the precocious group.

Generally, the genotypes at the NM-AIST site revealed higher grain yield than those grown at Kibosho. BBR proved to be the best yielder where 4306kg/ha and 3917kg/ha were obtained at MN-AIST and Kibosho, respectively and further studies can be conducted to test different fertilizers with respect to Tanzanian soils. Clay loam textural class for NM-AIST site influenced grain yield performance of quinoa genotypes while the Kibosho site had sandy soil that limited the grain yield.

These findings agreed with Razzaghi *et al.* (2012) where soils with higher proportions of clay (sandy clay loam) were suitable for the growth of quinoa when compared to sandy loam and sandy soils. The sandy clay loam soils registered the highest crop nitrogen up-take evapotranspiration and yield compared to the sandy loam and the sandy soil conditions. On the other hand, Präger *et al.* (2018) noticed significant differences in yield between seasons which correlates with this study. This proves how quinoa performs better in a more favorable environment. Similarly, Maliro *et al.* (2017) reported significant differences in grain yields between genotypes and between two sites, whereby, higher yields were obtained under the rain-fed condition at Bunda than Bembeke which was under irrigation.

The harvest index indicates the reproductive efficiency of the quinoa (Fuentes and Bhargava, 2011). The reduction in plant height normally lowers the dry weight of the vegetative part of the biomass that results in an increased harvest index just as the case in quinoa. This study revealed that late maturity genotypes grew taller than the genotypes that matured early in this study. These results were supported by what Spehar and Santos (2005) reported, however with exceptions for harvest index. Low values for late and high values for early maturing genotypes, which shows the possibility to develop quinoa for high grain and biomass productions to fit the farming systems. Seed size was influenced by the inherent factors of the genotypes. The findings are in line with, Maliro *et al.* (2017) where he reported a significant difference among the genotypes and none between sites (Bunda under rain-fed and Bembeke) under irrigation. However, this was contrary to Pulvento *et al.* (2010) where KVLQ520Y quinoa genotype grown under rain-fed conditions under different sowing dates in a Mediterranean environment in South Italy, seed size differed between seasons.

Conclusion

In the study, different genotypes of quinoa performed differently in the two sites; NM-AIST and Kibosho. Nevertheless, the fact that quinoa genotypes have been able to grow under the Arusha weather conditions displays the potential of the crop to be introduced to Tanzania. Of the tested quinoa genotypes, the BBR genotype performed better in both sites in terms of growth and yield parameters, days to 50% flowering and maturity, panicle length, biomass and yield. NM-AIST site had the highest performance in all the growth parameters of the genotypes as compared to the Kibosho site.

Following the performance of quinoa in all the two sites, we report the first introduction of quinoa to Tanzania and propose further studies to continue evaluating a diverse number of genotypes to select for genotypes adapted to specific environmental conditions promote quinoa cultivation in Tanzania.

Disclosure of conflicts of interest

The authors declare no conflict of interest.

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